

LASER INDUCED PLATE WAVES USING WAVEFORM SHAPING OPTICS AND STRAIN SENSING BY FIBEROPTICS CROSS-SENSITIVITY EFFECT

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INTRODUCTION

Aircraft are being used in service significantly longer than their original design life. This cost driven measure is subjecting aircraft structures to conditions that are increasing the probability of failure, particularly as a result of aging. Aircraft that already endured a long service life of more than 35 years are now being considered for additional 45 service years. This issue of long term usage and aging of aircraft is relevant to both military and commercial aircraft. The 1988 failure of the Boeing aircraft, which was operated by Aloha Airlines, heightened the level of attention of aircraft manufacturers, users and the Federal Aviation Administration (FAA) to the aging commercial aircraft. The increased usage of old aircraft has added a great degree of urgency to the ongoing need for reliable and efficient NDE methods of flaw detection and characterization in aircraft structures. Current technology is time consuming, demands great attention to details by the inspectors and, in many cases, requires a costly disassembly of the structure. The reliability of the test results depends heavily on the type of instrumentation that is used, the condition of the instruments, the methods and environment under which they are used and above all, the interpretation of the inspectors. While a large variety of NDE methods are available for inspection of aircraft structures, the speed of inspection, the need for coupling, and other constrains are imposing limitations on the field use of such methods.

Recent studies with plate waves [1] and particularly leaky Lamb waves have shown effective capabilities of quantitative evaluation of plate structures such as bonded joints and composite materials. Plate wave NDE methods can be used to determine the elastic properties of the adhesive and the composite laminates as well as to detect and characterize flaws. Models were developed assuming in the case of composite materials that they consist of transversely isotropic layers [e.g., 1-3]. Dispersion curves (phase velocity as a function of the thickness x frequency) are measured and are used to determine the properties by an inversion algorithm. Generally, a homogeneous composite laminate with the symmetric axis parallel to the surfaces supports the formation of two modes of propagation: symmetric and antisymmetric. The lowest symmetric (extensional) and antisymmetric (flexural) modes are the easiest to measure in an ultrasonic experiment and their velocity values are used to determine certain material constants. Unfortunately, the transmission of the ultrasonic signals for the leaky Lamb waves experiments require the use of water immersion or water injection through squirters. This water-coupling requirement restricts the field applicability of the method and is limiting the number of constants that can be measured. Particularly, the constant c_{11} is difficult to determine due to need for a pitch catch setting with small incidence angles. The application of a contact coupled guided wave methods offer the potential for the transition of plate wave techniques to field inspection.

Efforts to develop contract type plate wave techniques were made by numerous investigators (see for example [4]). The flexural wave signals are mixed with reflected signals from the boundary if the lateral dimension of the specimen is small in relation to the wavelength or the structure geometry is complex. In this case, only the extensional mode can be identified clearly. The issue of the mode identification in contact coupled plate waves is currently under investigation, and the practical implementation is still unsatisfactory. Recently, the authored started addressing this issue by developing a shaped wave-front laser induced ultrasound and fiberoptics receiving technique with a broader goal of integrating all the laser induced NDE methods into a single system.

SOURCE SHAPING OF LASER INDUCED ULTRASOUND

Laser induced pulses are now being routinely used (McClellan Air Force Base, Boeing and others) to create the equivalent of pulse-echo C-scan. Typically, such systems use lasers with pulse duration from about 10-ns to 50-ns. This short pulse duration makes these devices ideal for pulse-echo applications. However, the transition to other laser induced ultrasonic methods is still in its infancy. At UTEP, a system is currently under development where the pulsed laser beam that illuminates the test surface is tailored by an optical setup. A schematic view of the setup is illustrated in Figure 1. The emphasis is currently being made on producing a line source and to increase the pulse duration to induce plate waves. Ultrasonic plate waves are measured using a piezoelectric receiver that is placed at 10 cm from the line source and moved with a micrometric positioning device, taking measurements at each location. The input signal is measured with a photo diode mounted at the laser source. The input and the transducer signals are captured as a function of time. The double transfer function is then obtained to provide figures of the signals amplitude as a function of frequency and wave number. Peaks in this graph typically indicate the presence of the plate modes. These efforts are made to identify the induced modes to study the dispersive characteristics of the plate waves. At the initial phase, aluminum samples were subjected to this test procedure. One of the problems associated with this experiment is the presence of the modes at higher frequencies. These modes are excited because of the short pulse of the laser pulse. To circumvent this problem, the laser pulse duration is being extended using a beam splitter and the laser beam is then redirected onto its original path.

OPTICAL FIBER SENSORS OF ULTRASONIC DISPLACEMENTS

To sense the induced plate waves without couplant, fiber-optic sensors were developed. Generally, optical fiber-based sensors have been developed during the past twenty years for the measurement of a wide range of physical parameters including strain, temperature, refractive index and electromagnetic fields [5]. Their potential advantages include high resolution, small size, an immunity to electromagnetic interference (EMI) and capability for multiplexing. For the detection of ultrasonic waves, optical fiber strain sensors may be used if the geometry of the sensor can be arranged so that one component of the ultrasonic field produces displacements along the length of the sensor element. In particular, extrinsic Fabry-Perot interferometric (EFPI) sensors were investigated for this application, towards application to this joint study. These types of sensors allow easy detection of the field displacements using "free-floating" sensor designs [6].

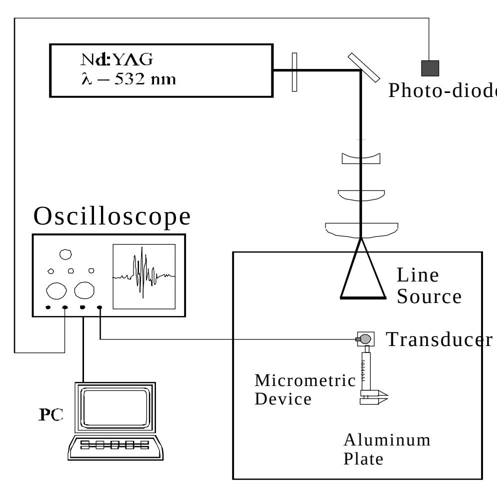

Figure 1: Laser ultrasonics setup.

RESULTS

Laser induced plate wave signals were investigated, where typical input signal as measured with the photo-diode and the corresponding transducer signal are shown in Figure 2. These measurements were repeated 32 times by displacing the transducer 0.5-mm each time. All the acquired signals were then used to form a double FFT in order to express the measurements as a function of the frequency and wave numbers. Figure 3 shows the results of the double FFT, where a predominant peak can be seen at about 270 KHz with a matching wave number of 900 (1/mm) corresponding to the fundamental anti-symmetric mode.

To examine the induced plate waves, optical fibers are being investigated as part of a vision of so-called "smart" structural material systems that contain the means for their own self-analysis. By orienting multiple optical fiber sensors so their long axes are perpendicular, the direction of propagation of ultrasonic fields will be determined. Results of the current studies are showing capability of detecting ultrasonic waves at frequencies that are greater than several MHz [6]. An issue that is being also studies is the influence of the fiber attachment to the surface. This attachment determines how components of wave displacement at the sensor location are coupled to the sensor and it requires additional analysis and experimental validation.

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REFERENCES

1. Y. Bar-Cohen, A. K. Mal and S. -S. Lih, "NDE of Composite Materials Using Ultrasonic Oblique Insonification," *Materials Evaluation*, Vol. 51, No. 11, (Nov., 1993) 1285-1296.
2. V. Dayal and V. K. Kinra, "Leaky Lamb Waves in an Anisotropic Plate. II: Nondestructive Evaluation of Matrix cracks in Fiber-Reinforced Composites," *J. Acoustic Society of America*, Vol. 89, No. 4 (1991), pp. 1590-1598.
3. R. D. Mindlin, "Waves and Vibration in Isotropic, Elastic Plates", *Structural Mechanics*., (1960), pp. 199-232.
4. M. Gorman, *J. Acoust. Soc. Am.* Vol. 90, No. 1, (1991), pp. 358-364.
5. E. Udd, (ed.), *Fiber Optic Smart Structures*, John Wiley, New York, 1995.
6. T. Tran, W. Miller, K. Murphy, A. Vengsarkar and R. Claus, "Stabilized Extrinsic Fiber-Optic Fizeau Sensor for Surface Acoustic Wave Detection," *J. Lightwave Technology*, Vol. 10, No. 10, (Oct. 1991), 1499-1506.

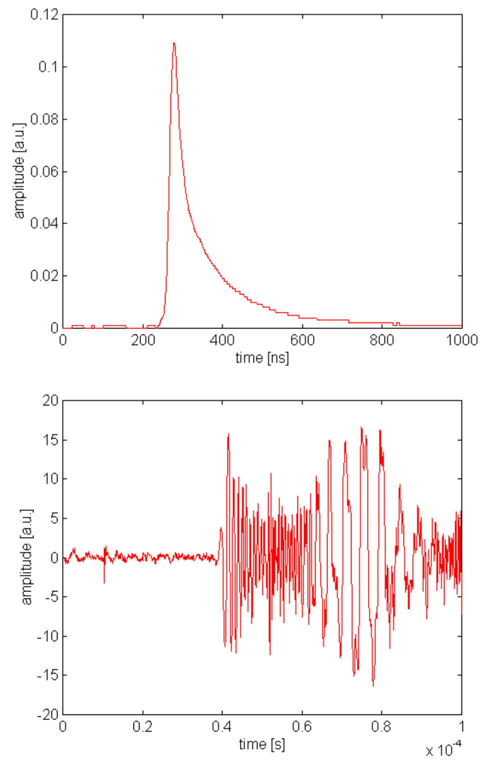

Figure 2. Typical laser input (top) and received ultrasonic (bottom) signals.

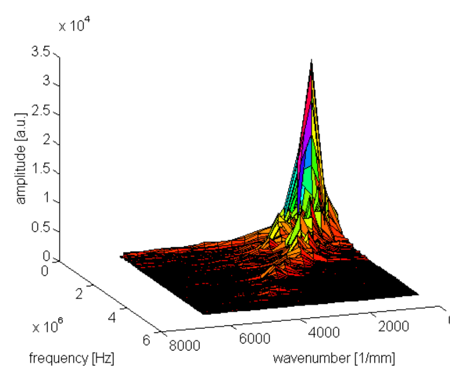

Figure 3. Typical double transfer function showing the anti-symmetric first modes.